

Tomato Acidity and the Safety of Home Canned Tomatoes

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Fifty-eight cultivars of tomatoes were screened for the occurrence of high pH fruit. Although large differences in pH were found between and within cultivars, no pH values high enough to permit the growth of *Clostridium botulinum* were obtained. pH and titratable acidity were not highly correlated. Tomato acidity data obtained from 57 locations in 23 states for 356 cultivars and 212 breeding lines were compiled and analyzed to identify trends. These data show that small-fruited, light colored and "new" cultivars are not low in acid, as is commonly believed. A few high pH data points ($\text{pH} \geq 4.7$) were associated with specific cultivars, locations, and conditions (overripening). The response of some higher pH cultivars to acidulation with citric acid was determined; a linear relationship between pH and added acid was found. These data were used to evaluate several methods of acidulation recommended for home canners.

Considerable public concern over the risk of botulism from home canned tomatoes has been expressed. This has been engendered in part by recent magazine articles and news items, some of which unfortunately contain inaccurate and misleading information. It has been stated, for example, that "new strains of tomatoes," including "pale yellow-orange tomatoes as well as small cherry or patio ones," contain insufficient acid to prevent the growth of *Clostridium botulinum* (15). Such statements may also imply that the consumer of home canned tomatoes faces a significant danger.

The seriousness of botulism should never be understated. However, we believe that the risk to consumers of home canned tomatoes is very small. Data compiled by the Center for Disease Control, U.S. Department of Health, Education, and Welfare (5), show only 3 outbreaks of botulism due to home canned tomatoes in recent years, none fatal. Furthermore, none of these outbreaks was documented as being associated with low acid tomatoes.

Few subjects have been presented to

the public more inaccurately (or more imaginatively) than tomato acidity. Many cultivars, especially the light colored and small tomato types, have been described in seed catalogs as "low-acid," "non-acid," or "acid-free." However, pH and acidity data for these varieties usually do not substantiate such descriptions (9, 16). According to Lambeth et al. (8), the 'Orange Jubilee' tomato, which is advertised as a "low acid tomato," is actually high in acid. However, it is also high in sugar, which may mask the acidity. Mild tasting tomatoes may be erroneously classified as low acid tomatoes. Valid data on the acidity of tomato cultivars have been obtained in a number of laboratories but this information is widely scattered in the scientific literature. The National Canners Association conducted nationwide surveys of pH variation in a number of cultivars of canning tomatoes in 1959 and 1961 (6). They reported that 6-7% of the individual samples exceeded pH 4.5. In a more recent survey of California canning tomatoes, fewer than 1% exceeded pH

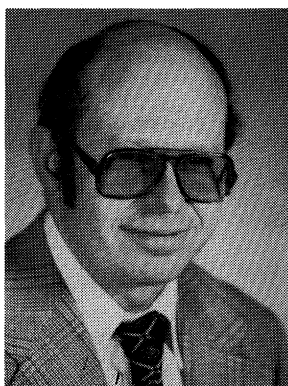
4.5 (8). National Canners Association data (2) indicate that *Clostridium botulinum* will not grow and produce toxin below pH 4.8. Tomato acidity and its relationship to botulism have been discussed in some detail by Powers in his recent review (12).

Research on tomato acidity and the safety of home canned tomatoes has been carried out by the Agricultural Research Service of the U.S. Department of Agriculture. At the Eastern Regional Research Center in Philadelphia, we have conducted measurements of tomato acidity in cultivars obtained locally and from the Beltsville Agricultural Research Center, and we have compiled data provided by a number of State Agricultural Experiment Stations for many additional cultivars grown nationwide. We have also conducted some preliminary studies of the acidulation of low acid tomatoes.

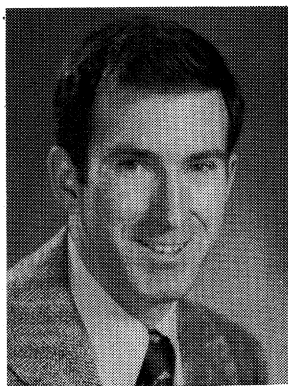
The results of our research provide the public with a factual basis for assessing the safety of home canned tomatoes and identify areas requiring additional study.

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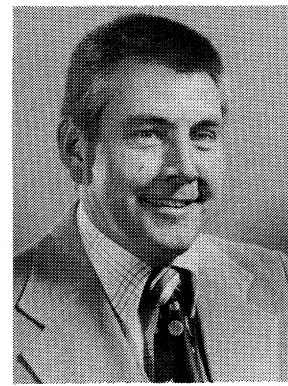
²We wish to acknowledge the assistance of Lois Stringer of the W. Atlee Burpee Co., Fordhook Farms, Doylestown, Pennsylvania, who provided us with a number of tomato cultivars for our screening study. We also wish to acknowledge the technical assistance of Robert Geter, Bernard Rogus, Alberta Jones, O. Panasiuk, and S. P. Graham, who participated in the analytical studies and data compilation at ERRC. Finally, we wish to thank the many scientists at SAES and USDA laboratories who contributed data for our compilation.



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Acidity of tomato cultivars evaluated by ERRC

During the summer of 1975, we carried out a survey of 58 tomato cultivars grown in Doylestown, Pennsylvania, and in Beltsville, Maryland (Table 1). These represent a number of standard, light-colored and pear-shaped cultivars, some of which have been described in seed catalogs as being "low-acid" or "mild". All cultivars were screened by measuring the pH of 5-18 individual fruits. Table-ripe tomatoes were washed, quartered, and blended for 2 min at high speed with a Waring blender (Model 5010)³. The pH measurements were performed using a Beckman Century SS expanded scale pH meter with a general purpose glass electrode and a sleeve junction calomel electrode. The meter was standardized using pH 4.00 buffer.

Cultivars showing a tendency toward high pH were identified by calculations of the probability that individual fruit would exceed pH 4.6 based on the sample mean and standard deviation. The higher pH cultivars were resampled, and many individual tomatoes were analyzed for pH and titratable acidity. Acidity was determined using a 10 g aliquot of blended tomato diluted with 40 ml distilled water and titrating with 0.1 N NaOH to a pH 8.1 endpoint.

³ Reference to brand or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

These data (Table 2) generally confirmed the results of the screening study; discrepancies for some cultivars were probably due to changes in composition resulting from climatic factors and ripening during the 1 or 2 week interval between samplings for the analyses. None of the cultivars which we examined had a mean pH high enough to support the growth of *Clostridium botulinum* (pH \geq 4.8). This was also true for the individual fruit comprising each sample, although pH varied substantially within the samples. However, the tendency of a cultivar to exceed pH 4.6 should be considered as a warning sign since atypical growing conditions and over-ripening might result in even higher pH values. Cultivars tending towards high pH were generally standard or pear types and not the white or yellow tomatoes often alleged to be low acid. 'Ace 55 VF,' 'Garden State,' and 'Big Girl' showed significant probabilities of exceeding pH 4.6 but not 4.8.

The correlation between pH and titratable acidity in the lower acid tomato cultivars was relatively poor. Similar results were reported by Lower and Thompson (10) and by Paulson and Stevens (11). The distinction between pH and titratable acidity in tomatoes as well as the poor correlation between these parameters should clearly be understood by seed merchandizers, extension specialists, and others who provide such information to the public.

Compilation of tomato acidity data

Many tomato cultivars are available to the home canner, and many new ones are introduced every year. It would be an impossible task for any one laboratory to carry out a comprehensive survey of all cultivars, and equally important, all growing conditions and locations. Consequently, during the winter of 1975-76, we solicited information from all state agricultural experiment stations (SAES) and USDA laboratories engaged in tomato research to supplement our own work on tomato acidity. We received a large volume of current (1974 and 1975) data from these laboratories including information on 356 cultivars and 212 current breeding lines from 57 different locations in 23 states. These data have been sorted and analyzed statistically, and important trends are described below.

The public has been told repeatedly that light-colored and small tomato cultivars are low in acid and should not be canned. Data summarized in Table 3 show the fallacy of this myth. The small and light-colored varieties tended to be higher in acid (lower pH) than other tomato types; "square," pear, and elongated tomato cultivars developed for commercial processing were somewhat higher in pH. The pH range for standard tomatoes was so great as to make any generalizations about their suitability for home canning meaningless.

It is equally fallacious to single out "nev" tomato cultivars as being low in

Table 1. pH of tomato cultivars screened by ERRC.

Cultivar	No. of fruits analyzed	pH		Cultivar	No. of fruits analyzed	pH	
		Mean	SD			Mean	SD
Ace	15	4.47 ^z	0.01	Jet Star	15	4.35	0.09
Ace 55VF	18	4.54 ^z	0.07	Jubilee	10	4.22	0.10
Avalanche	16	4.34	0.11	Manalucie	15	4.25	0.09
Beefmaster	7	4.19	-----	Marion	15	4.30	0.09
Beefmaster Hybrid	13	4.47 ^z	0.07	Marglobe	15	4.18	0.14
Beefsteak	15	4.23	0.10	New Snowball	15	4.16	0.06
Belgian Giant	8	4.33	-----	Orange Queen	15	4.30	0.11
Better Boy	15	4.28	0.11	Oxheart	5	4.30	-----
Big Boy	15	4.37	0.08	Pearson Improved	15	4.19	0.08
Big Early Hybrid	15	4.53 ^z	0.16	Ponderosa	6	4.32 ^z	-----
Big Girl	15	4.54 ^z	0.13	Ponderosa Pink	15	4.37 ^z	0.13
Big Set	16	4.50 ^z	0.09	Ramapo	15	4.16	0.08
Bur	15	4.37	0.08	Roma VF	15	4.34 ^z	0.12
Burpee VF Hybrid	16	4.50 ^z	0.10	Royal Chico	15	4.58 ^z	0.07
Campbell 17	15	4.15	0.08	Rutgers	15	4.29	0.07
Campbell 28	18	4.37	0.11	San Marzano	15	4.68 ^z	0.09
Campbell 1327 ^y	15	4.27	0.06	Spring Giant	14	4.18	0.07
Campbell 1327 ^x	16	4.39	0.09	Spring Set	13	4.40	0.08
Delicious	13	4.54 ^z	0.13	Stokes Alaska	12	4.06 ^z	0.14
Early Giant	15	4.15	0.09	Sunnybrook Earliana	13	4.37 ^z	0.15
Early Girl	16	4.14	0.07	Sunray	15	4.21	0.06
Fantastic	12	4.26	0.16	Supersonic	15	4.25	0.07
Fireball	13	4.50	0.16	Tropic	15	4.28 ^z	0.08
Gardener's Delight	15	4.18	0.11	Valiant	15	4.37 ^z	0.13
Garden State	15	4.48 ^z	0.08	Walter	15	4.16	0.09
Globemaster Hybrid	15	4.42	0.08	White Queen	16	4.21	0.08
Golden Boy	15	4.17	0.08	Wonder Boy	15	4.41 ^z	0.08
Golden Queen	15	4.26	0.11	Yellow Pear	15	4.40 ^z	0.13
Heinz 1350	15	4.20	0.06	Yellow Plum	15	4.31	0.06
Homestead	15	4.20	0.09				

^z Larger sample analyzed subsequently to verify result.

^y Obtained from Beltsville, Md.

^x Obtained from Doylestown, Pa.

Table 2. The pH and titratable acidity of relatively low-acid tomato cultivars screened by ERRC.

Cultivar	No. of fruits analyzed	pH		Estimated frequency pH $\geq 4.6^z$	Estimated frequency pH ≥ 4.8	Mean titratable acidity (%) ^y	Correlation coeff. pH vs. tit. acidity
		Mean	SD				
Ace	54	4.45	0.11	0.067	0.000	0.399	-0.34
Ace 55VF	25	4.55	0.09	0.289	0.003	0.302	-0.41
Beefmaster Hybrid	29	4.39	0.13	0.053	0.001	0.363	-0.44
Big Early Hybrid	40	4.42	0.12	0.051	0.000	0.308	-0.68
Big Girl	45	4.50	0.11	0.159	0.001	0.305	-0.58
Burpee VF Hybrid	46	4.37	0.11	0.018	0.000	0.350	-0.56
Garden State	49	4.52	0.10	0.242	0.004	0.389	-0.59
Royal Chico	23	4.48	0.07	0.023	0.000	0.291	-0.40
San Marzano	56 ^x	4.47	0.07	0.032	0.000	0.308	-0.55
Valiant	33	4.41	0.13	0.072	0.000	-----	-0.76

^zProbability of occurrence of tomatoes exceeding pH 4.6 based on sample mean and SD, assuming pH values for cultivar are normally distributed. Frequency $\times 100 = \%$.

^yCalculated as g citric acid per 100 g tomato, fresh wt.

^xAs 28 sets of 2 because of small fruit size.

acid. Cultivars in our compilation were sorted according to introduction date to determine whether tomato acidity was changing with time. Data shown in Table 4 indicate no consistent change over 25 years. New cultivars may be lower or higher in acidity than old ones. It is true that certain newer cultivars, developed for mechanical harvesting rather than for home gardening, are somewhat higher in pH. This is evident in the breeding line data which contain many examples of such types. It is important that the pH and acidity of breeding lines be considered along with other quality attributes prior to their introduction as new cultivars.

Although low-acid tomatoes may not fit the stereotype described by the media, they do exist, albeit infrequently. The occurrence of high pH data in our compilation is shown on Table 5. Most of the high pH data points were obtained in a few locations and may be characteristic of the cultivar or indicative of abnormal growing conditions, overripe samples or questionable analytical procedures. With the exception of the last factor, these conditions may represent a potential hazard and should be verified. The National Canners Association surveys (6, J. R. Kimball, National Canner Assoc., personal communication) also included a very few high pH data points.

Growing location undoubtedly has an influence on tomato acidity. However, no regional trends were noted when the pH data points were sorted by state. Certain locations in Iowa, California, and Michigan produced exceptionally high pH values; such data may reflect highly localized rather than area-wide conditions.

Any attempt to rank tomato cultivars by pH and then draw conclusions about their suitability for home canning must be done with extreme caution. We are reluctant to make any such recommendations without further verification of the data (which is not our own and consequently impossible

Table 3. pH of Different Tomato Types^z.

Type	No. of cultivars	pH mean	Range
Cherry	12	4.2	3.9-4.5
Patio	1	4.2	4.2-4.3
White	3	4.2	4.2-4.3
Yellow	5	4.2	4.1-4.3
Orange	6	4.3	4.2-4.4
Pear	14	4.4	4.3-4.7
Elongated	7	4.5	4.3-4.6
"Square"	23	4.4	4.1-4.9
Standard	225	4.3	4.0-4.7

^zFrom compilation of SAES and USDA data.

to judge for accuracy). Nevertheless, we recognize the need to identify the cultivars which did produce high pH data points so that others can determine for themselves the magnitude of the problem. All high pH data points (pH ≥ 4.7) are identified in Table 6.

These data illustrate some of the factors that must be considered in

assessing the significance of a high pH data point. Is a cultivar consistently high in pH as with 'Ace' tomatoes, or is the high pH data point an exception as with 'Jubilee'? Do the high pH data points originate in one or several locations? What sampling procedures, replication, and analytical methods were employed? Were the tomatoes in the sample overripe? The latter consideration is especially relevant in view of the number of high pH data points ascribed by their originating laboratories to overripe tomatoes. Villarreal et al. (19), Thompson (17), Leonard et al. (9), and others have observed an increase in pH and decrease in titratable acidity during the ripening of tomatoes.

It may be that some of the cultivars for which we have compiled pH data are not suitable for home canning because of inadequate acidity. We hope to obtain additional information about the occurrence of high pH tomatoes.

Table 4. Tomato acidity — past, present, and future^z.

Year of introduction	No. of cultivars	pH		No. of cultivars	Titratable acidity	
		Mean pH	SD		Mean T. A. (%) ^y	SD
Before 1950	49	4.29	0.02	15	0.38	0.006
1950-1959	26	4.34	0.02	13	0.40	0.002
1960-1969	73	4.35	0.02	47	0.40	0.006
1970-1976	96	4.34	0.05	73	0.39	0.007
Current breeding lines	212	4.39	0.01	176	0.34	0.002

^zFrom compilation of SAES and USDA data.

^yCalculated as g citric acid per 100 g tomato, fresh wt.

Table 5. Incidence of high pH data points in tomato acidity compilation^z.

pH range	No. of data points	% of total	Location
Below 4.50	759	79.6	-----
4.50-4.59	121	12.7	-----
4.60-4.69	49	5.1	-----
4.70-4.79	14	1.5	Calif., Iowa, Mich., Miss., N.Y., Oregon
4.80-4.89	6	0.6	Iowa
4.90-4.99	2	0.2	Calif., Mich.
5.00-5.09	1	0.1	Iowa
5.10-5.19	1	0.1	Iowa

^zFrom compilation of SAES and USDA data.

Table 6. High pH data in compilation^z.

Cultivar	High pH	pH range excluding high	Mean pH	Data points	Location
Dorchester	5.15	4.37-4.50	4.70	4	Iowa
Knox	5.00	4.35-4.38	4.57	3	Iowa
Ace	4.95 ^y	4.38-4.76	4.67	4	Mich.
105-J4	4.90 ^y	-----	4.90	1	Calif.
UC 134	4.85	4.22-4.69	4.49	5	Iowa
Heinz 1350	4.82	4.20-4.50	4.38	10	Iowa
Supersonic	4.80	4.00-4.70	4.33	16	Iowa
Roma	4.80	4.27-4.55	4.54	3	Iowa
Jubilee	4.80 ^y	4.06-4.40	4.30	8	Iowa
Jet Star	4.80	4.12-4.70	4.42	29	Iowa
VF 105-2	4.78 ^y	4.57	4.67	2	Calif.
Ace 55VF	4.75	4.50-4.67	4.60	6	Miss.
Earlired	4.72	-----	4.72	1	Mich.
UC 105J4	4.72 ^y	4.46	4.59	2	Calif.
Big Set	4.72	3.98-4.40	4.31	12	Iowa
VF 317	4.70 ^y	4.31-4.50	4.45	6	Calif.
UC 105 long	4.70 ^y	4.50-4.60	4.58	5	Calif.
Setmore	4.70 ^y	4.10-4.65	4.39	18	Oregon
Peelete	4.70 ^y	4.39-4.60	4.52	5	Calif.
Coldset	4.70 ^y	4.30-4.40	4.47	3	Oregon

^zFrom compilation of SAES and USDA data.^yMay have been overripe.

Acidulation of lower acid tomatoes

The addition of acid to home canned tomatoes has been widely recommended as an "insurance policy," protecting consumers of such products from the possibility that tomatoes high enough in pH to permit the growth of *C. botulinum* might have been processed (7, 18). Acidulation of tomatoes for commercial canning has been studied extensively as a means of preventing "flat-sour" spoilage (9, 13, 14) and is permitted by the Food and Drug Administration (4).

We have attempted to estimate the acidulation requirements of the lower acid tomato cultivars in our study. Aliquots of blended individual tomatoes having a pH exceeding 4.5 were titrated with a 5% citric acid solution to reduce the pH stepwise by 0.1, 0.2, and 0.3 units. The relationship between pH and added acid was found to be approximately linear with each of the cultivars which we acidulated (Fig. 1). The slope of the pH versus added acid curve varied both between and within cultivars, depending on the buffering capacity of the tomatoes (Table 7). An estimate of the acidulation requirement for a cultivar can be calculated from the slope (pH change/added acid) and the target reduction in pH to be achieved. The minimum slope (corresponding to the most highly buffered tomato) for a cultivar should be used to assure that enough acid is added to provide for the worst case.

Table 8 shows the estimated pH reductions which would result in 6 lower acid tomato cultivars, according to the minimum acidulation curve slopes, if 4 current acidulation recommendations were followed:

- 1) 1/4 tsp citric acid per pint = 1.25 cc/473 cc (7, 18).
- 2) 0.1% citric acid (1).
- 3) 1 tsp lemon juice per pint = 5 cc/473 cc (18).
- 4) 1 tbsp lemon juice per pint = 15 cc/473 cc (3).

In these calculations, it was assumed that the acidity of the lemon juice was

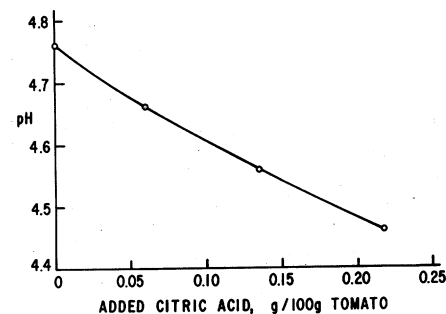


Fig. 1 Acidulation of pureed 'Ace' tomato.

equivalent to a 5% citric acid solution; analyses of representative products have shown this level of acidity to be typical for bottled lemon juice. The relative merits of acidulation recommendations depend on the pH reduction desired; a decrease of at least 0.2-0.3 pH units would be required with the highest pH tomatoes reported in our compilation and in the National Canners Association Survey (6). It is evident that the lower lemon juice recommendation (18) is inadequate and that the lower citric acid recommendation (1) is marginal. The higher levels of acidulation appear to be satisfactory with respect to pH reduction. In recommending an acidulation procedure for home canning, one must also take into account the

Table 7. Slope of acidulation curve for lower acid tomato cultivars.

Cultivar	No. tomatoes	Slope ^z	
		Minimum ^y	Pooled data ^x
Ace	7	1.36	1.47
Ace 55 VF	8	1.65	2.07
Big Early Hybrid	4	1.59	2.32
Big Girl	10	1.86	2.25
Garden State	10	1.48	1.70
Valiant	3	2.08	2.30

^zpH reduction/added citric acid (g/100g tomato), assuming linearity.^yFrom individual regression lines for each tomato in sample.^xFrom single regression line for all tomatoes in sample.

Table 8. Estimated pH reduction in lower acid tomato cultivars after acidulation.

Cultivar	pH reduction ^z			
	Citric Acid		Lemon Juice ^y	
	1/4 tsp ^x per pint	0.1%	1 tsp ^w per pint	1 tbsp ^v per pint
Ace	0.30	0.14	0.08	0.22
Ace 55VF	0.36	0.16	0.09	0.27
Big Early Hybrid	0.35	0.16	0.09	0.26
Big Girl	0.41	0.19	0.10	0.31
Garden State	0.33	0.15	0.08	0.24
Valiant	0.46	0.21	0.11	0.34

^zBased on minimum slope of acidulation curve for cultivar.^yContaining 5% citric acid.^x1 1/4 cc/473 cc.^w5 cc/473 cc.^v15 cc/473 cc.

availability, uniformity, and flavor of the acid.

Conclusions

Botulism has been attributed to home canned tomato products in only a few cases, none of which have been linked to a low acid tomato variety.

Tomato cultivars generally considered by the public to be "low acid," i.e., cherry, patio, white, yellow, and orange tomatoes, are not high in pH.

New tomato cultivars are not necessarily lower (or higher) in acidity than older ones. In our compilation, the pH of tomato cultivars introduced during the last 25 years has not shown any upward trend with time.

Considerable variation in acidity does exist among the many tomato cultivars available for home canning. Large samples may contain individual fruit having a substantially higher pH than the cultivar mean. None of the 55 cultivars screened for acidity at ERRC contained fruit high enough in pH to permit the growth of *Clostridium botulinum* (pH \geq 4.8). A few data points obtained in our compilation of experiment station data fall in the high pH range.

High pH data points may be related to cultivars, to specific locations, to overripening or to questionable methodology.

The pH and titratable acidity in lower acid tomato cultivars are not highly correlated.

In high pH tomatoes acidified with citric acid, the relationship between pH reduction and added acid was found to be approximately linear. The slope of this acidulation curve can be used to

estimate the pH reduction which would occur in lower acid tomatoes following acidulation procedures recommended by USDA and state extension specialists.

Research at ERRC on tomato acidity and the safety of home canned tomatoes is continuing. We are obtaining additional data on the occurrence of low acid tomatoes, and we are conducting home canning studies with such fruit and comparing alternative acidulation procedures. We are also investigating conditions which would enable *Clostridium botulinum* to grow in home canned tomatoes. The results of the work in progress will provide more definitive data for evaluating the safety of current procedures for the home canning of tomatoes.

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